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Enhancement of palm oil refinery waste – Spent bleaching earth (SBE) into bio organic fertilizer and their effects on crop biomass growth

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ABSTRACT

Spent bleaching earth (SBE) derived from the degumming and bleaching of crude palm oil (CPO) from physically refined palm oil is commonly disposed off at landfills at a high cost. Its disposal has so far led to environmental degradation but has not been addressed. This study demonstrates the innovative utilization of SBE as a bio organic fertilizer. The SBE was co-composted with some agricultural and palm oil milling by-products. Composted SBE has a positive impact on soil physical attributes for plant growth and microbial rejuvenation due to adequate amounts of beneficial mineral elements; improved organic carbon (OC); cation exchange capacity (CEC); water-holding capacity and C:N ratio. The pot and field trials carried out indicate highly significant increases in the productivity of okra (*Abelmoschus esculentus*), kangkung (*Ipomoea aquatic*) and groundnut magenta with 2-fold increases (35–60%) on average in fresh and dry matters production.

1. Introduction

Pre-treatment of crude palm oil (CPO) during a refining process which involves degumming and bleaching, generates plentiful of spent bleaching earth (SBE). Bleaching earth is a very fine powder and its main component is silicon dioxide (~57% and more depending on the type). It is prepared by treating montmorillonite clay (represented by $Al_2O_3{\cdot}4SiO_2{\cdot}nH_2O$) with mineral acids and by eluting basic components such as aluminium, iron and magnesium. Bleaching earth has been used to absorb dark colour matters and odour-causing substances in crude oil and vegetable oil. It is estimated that about 600,000 metric tonnes or more of bleaching earth was utilized worldwide in the refining process based on the worldwide production of more than 60 million tonnes of oils (Park et al., 2004).

SBE is a discarded palm oil refinery (POR) waste containing a high percentage of residual oil (~20–40%) (Aziz et al., 2001; Loh et al., 2006). Disposal of SBE by incineration, inclusion in animal feeds, land filling method or concrete manufacturing is generally practiced. Currently in Malaysia, the most common practice is disposal at landfills – causing fire and pollution hazards due to the degradation of the residual oil in it, and the associated greenhouse gas (GHG) emissions upon its disposal. In Japan, SBE has been incinerated for cement manufacturing but there is difficulty in maintaining good cement quality due to the high concentration of oil in SBE (Park et al., 2004). In the near future, incineration or landfill disposal will probably become impossible due to a stricter environmental regulatory restriction, lack of new dump sites and most importantly, the release of GHG to the atmosphere at landfills.

The residual oil in SBE should ideally be recovered and re-used for industrial applications in order to reduce cost in oil processing. Adding value to the recovered residual oil is among the many possible approaches to resolving the issue e.g. as feedstock for biofuels (Loh et al., 2006), biolubricants (Loh et al., 2007), industrial grade oleochemicals (Chanrai and Burde, 2004) and animal feeds (Damodaran, 2008). Apparently, the de-oiled SBE without any known applications was destined at landfill as required by the local authorities. SBE without residual oil recovery can also be used as feed material (Ng et al., 2006). Other attempts on SBE utilization include regenerating SBE as adsorbents (Cheah and Siew, 2004), fermenting oil-containing SBE to produce riboflavin for use in medicine, food and fodder industries and recovering riboflavin-free SBE-based soil conditioner without much evidence given (Park et al., 2004). In recent years, waste clay and recycled bentonite in either their original forms, or co-composted with rice husk, rice husk ashes, chicken litter and other beneficial biomass

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or agriculture by-products as a soil amendment was extensively researched (Arias-Estévez et al., 2007; Croker et al., 2004; Ho et al., 2010; Soda et al., 2005; Wang et al., 2010). For example, an organic-rich bentonite-based waste particularly generated from the wineries was found as a suitable acid soil amendment to facilitate soil–plant interaction for increased soil fertility, microbial rejuvenation and biomass productivity at lower addition rates (Nóvoa-Muñoz et al., 2008). Besides, its negatively charged soil surface can also immobilize heavy metals and pesticides in controlling leaching of these contaminants into waterways (Bermúdez-Couso et al., 2011; Pateiro-Moure et al., 2009).

To date, the PORs in Malaysia are still dumping SBE at landfills because there are no available scientific solutions to address the problem. Therefore, the main objective of the present study focused on 100% recovery and conversion of SBE into a bio organic fertilizer by co-composting it with some agricultural and palm oil milling by-products. It was envisaged that the composted SBE possessed good characteristics for soil remediation resulted in improvement of crop productivity, and hence overcoming the low chemical fertilizer application efficiency in agriculture that destroys mother earth. It provides a total environment solution to abate the pollution problems created in the disposal of SBE.

2. Methods

2.1. Materials

Bulk supply of SBE was sourced from 2 PORs at Pasir Gudang on a regular basis. Two types of SBE commonly used by the refineries are acid-activated SBE and natural SBE. The SBE used can be in different conditions i.e. freshly released or stored. The SBE from the refinery was discharged into a silo and directed to a closed loop system i.e. a dedicated buffer storage container placed with a quick-connect SBE transfer system to ensure spill-proof handling of SBE from refinery to haulage truck en route to the SBE recovery plant.

2.2. Pilot setup of a SBE recovery plant

A pilot SBE recovery facility was established at Pasir Gudang. The pilot plant was equipped with an open door and a closed door composting systems having composting piles of about 8′ (height) × 8′ (width) × 16′ (length) at the initial 30 days and enlarged at 18′ × 24′ × 60′, respectively after 60 days on maturity.

2.3. Formulation and production of SBE-based bio organic fertilizer

The SBE collected was first sorted out to remove any unwanted substances arising from the dumping of other wastes during oil refining process. It was subjected to a 90 day co-composting phase with chicken litter (∼25%) and palm oil milling by-products (∼40%) i.e. empty fruit bunches (EFB), palm oil mill effluent (POME) and shredded oil palm trunks (OPT). The type and blending ratio of the feedstock used were dependent on the desired nitrogen–phosphorus–potassium (NPK) contents for the finished product formulated. Modification of C:N ratio was also conducted via different blending ratios. The composting was conducted at 30–50 °C in open door and closed door windrowing systems to facilitate aeration via mechanical turning and to encourage active microbial growth in SBE. Agitating with aeration was conducted regularly for a complete homogeneous and effective mixing.

2.4. Pelletization of SBE-based bio organic fertilizer

The SBE-based bio organic fertilizer (bio materials) was pelletized via a modified pelletizer involving steps such as feeding, pelletizing, and separation, drying and packing. The bio materials were fed manually to the pelletizer which was equipped with dies of 2 sizes (4 and 6 mm) rotated by a belt system. The pelletizing process was conducted at an ambient temperature to <60 °C (max). The pellets coming out from the pelletizer were separated into 70% pellets and 30% flake materials. The pellets were dried using a heater at 30–40 °C for 6–12 h.

2.5. Analyses

The pH of the samples was measured by a pH metre in deionized water at a sample/water ratio of 1:5 (Soda et al., 2006). Total organic carbon (TOC) and organic matter content were determined by wet oxidation using the Walkley–Black dichromate digestion method (Ho et al., 2010; Rayment and Higginson, 1992; SIRIM, 1980; Soda et al., 2006; Walkley and Black, 1934; Zulkifli and Masnon, 1993a). The factor used to convert TOC to organic matter was 1.724 (Chen et al., 2004; Zulkifli and Masnon, 1993a). Total N was determined according to ASTM (2002) using an elemental analyzer CNS-LECO 2000. The C:N ratio was calculated from the measured values of TOC and total N. The cation exchange capacity (CEC) was determined using 1 M NH_4-acetate buffered at pH 7.0 (Rayment and Higginson, 1992; Soda et al., 2006; Zulkifli and Masnon, 1993d). The water-holding capacity was measured according to ASTM (2010). The moisture content was measured according to ASTM (2009) using LECO TGA 701. The nutrient content: N by either Kjeldatherm digestion method (Zulkifli and Masnon, 1993b) or using CNS-LECO 2000; Available P (as P_2O_5) was determined using the molybdenum blue method and colour formation was measured by UV/vis spectrophotometer at wavelength 880 nm according to Zulkifli and Masnon (1993c); K, Ca, Mg and other trace elements were extracted using concentrated HCl and concentrated HNO_3 and then determined using a flame atomic adsorption spectrometer (AAS) Perkin Elmer Analyst 400. The residual oil from SBE was recovered via solvent extraction system (soxtherm) according to method described previously (Loh et al., 2006). The microbial growth study was conducted using spread plate method in nutrient agar with 3 times dilution of the centrifuged supernatant SBE solution (1 mL of supernatant in 9 mL of 0.85% salt water repeated for 3 times). The results were addressed as colony form unit (CFU/mL).

2.6. Pot assay

The small scale pot assays of SBE-based bio organic fertilizer on plant growth assessment was carried out on (1) *Ipomoea aquatic* or kangkung, (2) *Abelmoschus esculentus* or okra. The PVC pots measured 12 cm and 25 cm in height and 12 cm and 25 cm in diameter, respectively were filled up with the treatment and control soils to about three quarters full. The soil used was sandy loam pre-mixed with compost (commercially available) with a moisture of 45–55%, pH 5.5–6.5 and C:N 25–35 (Table 4).

2.6.1. Ipomoea aquatic (kangkung)

A randomized block was designed having two fertilizer treatments: (A) blank and (B) a compost soil with SBE-based bio organic fertilizer. All treatments were replicated three times. Parameters observed were average number of leaves and average height of kangkung. The fresh weight of total biomass, shoot and root were measured and used in a statistical analysis.

2.6.2. Abelmoschus esculentus (okra)

Two sets of planting block were set up; each set contained 3 planting pots having different fertilizer treatment: (A) blank and (B) a compost soil with SBE-based bio organic fertilizer. All treatments were replicated three times. Seeds were soaked in water for 24 h to allow water to nourish the seed for better germination before

Table 1
Fertilizer value (NPK content) of various bio-based materials.

Component	N (%)	P (%)	K (%)	C:N
Spent bleaching earth (SBE)	0.06–0.71	2.01–2.36	0.27–0.84	290
Oil palm trunks (OPT)	0.19	0.07	1.21	155
Empty fruit bunches (EFB)	0.33	0.03	1.59	50–94
Oil palm fronds (OPF)	0.55	0.03	2.00	48–61
Mesocarp fibre	0.80	0.10	0.50	57
Palm oil mill effluent (POME-treated)	4.68	1.25	5.16	8
Chicken litter	1.08	2.22	2.25	7

planted. The physical parameters observed were plant height, root length, number of leaf, size of leaf and number of fruit. Two performance and efficacy assessments at different cultivation period were conducted i.e. in a month of cultivation and after a complete 3-month trial. The plants were harvested after the set cultivation periods. The physical parameters of the plant (fresh weight and or dry weight of the total biomass, shoot and root) were measured and used in a statistical analysis.

2.7. Field evaluation and efficacy test

A big scale field trial was conducted in cooperation with Jabatan Pertanian Negeri Perak at Kompleks Pertanian Titi Gantung under an agricultural programme by the Ministry of Agriculture. The tested crop was groundnut var. magenta on 0.5 ha cultivation land. The sandy loam soil used was loose with pH of 5.7–6.5. An application rate of 250 kg ha^{-1} of the SBE-based bio organic fertilizer was used throughout the trial. This rate was recommended by the Department as per the standard used based on the NPK requirements specifically for planting magenta groundnut. Ten plants were selected randomly for the monitoring of the plant growth performance in every fortnight starting from the application of the SBE-based bio organic fertilizer. At the end of the cropping phase, the fruits were harvested and measurement of their fresh weights conducted. The results were compared with that of the fresh fruit weights using commercial fertilizer commonly used by the Department.

2.8. Statistical analysis

A statistical analysis tool, *t*-test was used to analyze significance of treatment of SBE-based bio organic fertilizer on plant growth performance.

3. Results and discussion

Bio fertilizer production in the oil palm industry has so far concentrated mainly on the by-products from palm oil mills but has excluded the refinery waste (namely SBE) discharged by the PORs. SBE was found to contain a fairly adequate quantity of NPK compared to various other bio materials such as oil palm biomass (e.g. POME, EFB, OPT and oil palm frond or OPF) and agricultural by-products (e.g. chicken litter) (Table 1), which is essentially required in any bio fertilizer production. The initial C:N ratio of 290 in SBE before composting was far too high compared to other bio materials which could decompose readily in the field as mulch. Though SBE contained a high C with limited N, the bioavailability of C could be low, thus the decomposition of SBE being slow. Hence, the direct application of SBE to soil would have caused a detrimental effect in limiting bioavailability of soil N for plant growth.

3.1. Characteristics of SBE

Bleaching earth is montmorillonite and bentonite-based natural clay having similar characteristics as that of zeolite, thus hypothetically it mimics zeolite in many ways. It has essential mineral elements (N, P, K – Table 1; Ca, Mg, Zn, Fe, Mn, Cu, Ti – Table 2) and beneficial elements (Si, Na – Table 2) for potential use as a soil supplement for plant growth. The physicochemical properties of SBE after the bleaching process in oil refinery have not altered much compared to the fresh earth (Table 2). Furthermore SBE from POR adsorbs about 6 to 18% of residual CPO mainly palm-based fatty acids ranging from C14 to C18 which also contains important nutrient elements and phytonutrients (e.g. carotene, vitamin E, Table 3). Together the earth and the oil of SBE are relevant candidates in promoting plant growth and providing nutrients for microorganism rejuvenation. Regardless of the concentration and bioavailability of these nutrients in SBE, it is well established that the presence of P_2O_5 has a positive impact on the growth of flowers and fruits, while N and Mg affect leaves growth and K catalyzes photosynthesis. Hence, the presence of NPK is required in any form of fertilizer for overall plant growth. Based on the analyses, SBE has almost all the

Table 2
Characteristics of freshly manufactured bleaching earth, spent bleaching earth (SBE) and zeolite.

Characteristics	[a]Fresh bleaching earth	SBE	[b]Zeolite
Free moisture (%)	10.5	0–1.8	6.9
pH (20% suspension)	4.6	4.5–5.3	6.0–7.0
Chemical composition by ash (% oxides by wt)			
SiO_2	60.4	56.9	71
Al_2O_3	11.5	9.24	11
Fe_2O_3	9.3	8.27	1.61
MgO	5.2	4.32	1.01
CaO	1.7	3.9	2.51
Na_2O	0.4	0.08	1.70
K_2O	1.2	0.96	2.28
MnO_2	NA	0.10	0.05
TiO_2	NA	0.90	0.30
P_2O_5	NA	4.87	0.05

[a] Taiko Supreme 1B supplied by Taiko Clay Marketing Sdn. Bhd. (2006).
[b] Bionas Zeolite, national fertilizer for Bionas Bio-diesel Project.
NA: not applicable.

Table 3
Characteristics of residual oil of spent bleaching earth (SBE).

Characteristics	SBE
Residual oil characteristics	
Free fatty acids, FFA (%)	12.6
Peroxide value, PV (meq/kg)	3.4
Phosphorus, P (mg/kg)	18.7
Iron, Fe (mg/kg)	1.24
Copper, Cu (mg/kg)	0.38
β-Carotene (mg/kg)	6
Total vitamin E (mg/kg)	38.8
Fatty acid compositions, FAC (wt% as methyl esters)	
C14:0	1.0
C16:0	44.4
C18:0	4.7
C18:1	39.4
C18:2	10.5

Table 4
Characteristics of spent bleaching earth (SBE) before and after composting.

Fertilizer characteristic	SBE	SBE-based bio organic	Mineral soil	Soil: SBE-based bio organic (50:50)
Water holding capacity, ml/100 g	5.7–6.5	13–20	14	137–140
Organic carbon (%)	7.06	15.81–17.23	12–15	11.85
Organic matter content (%)	12.17	27.26–30.04	15–30	20.43
Cation exchange capacity, cmol/kg	8.03	31.5–36.0	29.2	32–39
C:N	290	9–21	25–35	32
pH	4.5–5.2	5.4–6.5	5.5–6.5	5.89

nutrients required for plant growth although not in an optimized level.

Another important aspect is that SBE contains Si and Al (Table 2) that strengthens the ability of soil to hold nutrients. Due to the isomorphous substitution of Si^{4+} by Al^{3+} in the mineral structure of the earth and the containment of the negatively charged organic matter in it, SBE has a net negative surface charge. The negative charge associated with isomorphous substitution is considered permanent, that is, the charge does not change with pH changes. In this case, when SBE is associated with soil, it enhances soil characteristics and strengthens the negativity of soil surface charges in exchanging the positively charged ions of common nutrients such as Ca^{2+}, Mg^{2+}, K^{+}, Fe^{2+}, Na^{+}, Mn^{2+}, Zn^{2+}, Cu^{2+} and Ni^{2+}. This further supports the increases of CEC in the presence of increased organic carbon (OC) in composted SBE.

Besides, a total pore volume of 0.165 $cm^3\,g^{-1}$ for the SBE is indicative of a material that is not as good an adsorbent as activated carbon (0.459 $cm^3\,g^{-1}$) but suffices to loosely bind the nutrients and release them slowly when needed by the crops. It shows adequate sorption/desorption capability. Once it is enhanced or composted, it increases water holding capacity, porosity and the adsorption capacity of nutrients. Unfortunately, there is not enough evidence at the moment to show that the structure and texture of composted SBE was indeed improved.

3.2. SBE-based bio organic fertilizer

Organic fertilizers are naturally occurring fertilizers or naturally occurring mineral deposits. In practice, organic fertilizers usually include mineral-based fertilizers as well, such as greensand or rock phosphate which is naturally occurring too. Organic fertilizer is produced naturally or via natural biological processes such as composting. The majority of nitrogen supplying organic fertilizers contain insoluble nitrogen and act as a slow-release fertilizer. SBE which is a naturally occurring montmorillonite/bentonite clay containing mineral deposits that is mined and physically treated into powder form without using chemicals. Hence, they can be considered organic. By co-composting SBE with other naturally occurring organic materials such as agricultural by-products and oil palm biomass, the composted finished products can still be considered as organic fertilizers.

3.3. Composting process

A significant problem in the reuse of SBE from vegetable oil processing is its hydrophobic nature in the presence of residual oil on its surfaces as well as its acidic nature. The average pH of the 1:5 extract SBE solutions (20% suspension) and the water-holding capacity of SBE were 4.9 and 6.1 mL/100 g, respectively. Through the co-composting of SBE with chicken litter and palm oil milling by-products, the chemical attributes of SBE were significantly altered. The average pH and water-holding capacity of the co-composted materials were 6.1 and 16.5 mL/100 g, respectively. The pH increased with the addition of co-composted material due to the alkaline nature and alkalinity generated through the composting process. The hydrophobic nature of SBE was high due to the presence of adsorbed residual oil associated with the bleaching process as was evidenced by the measurement of water-holding capacity, but the composted SBE showed an increased capacity in retaining water, thus declining in the hydrophobic nature. It

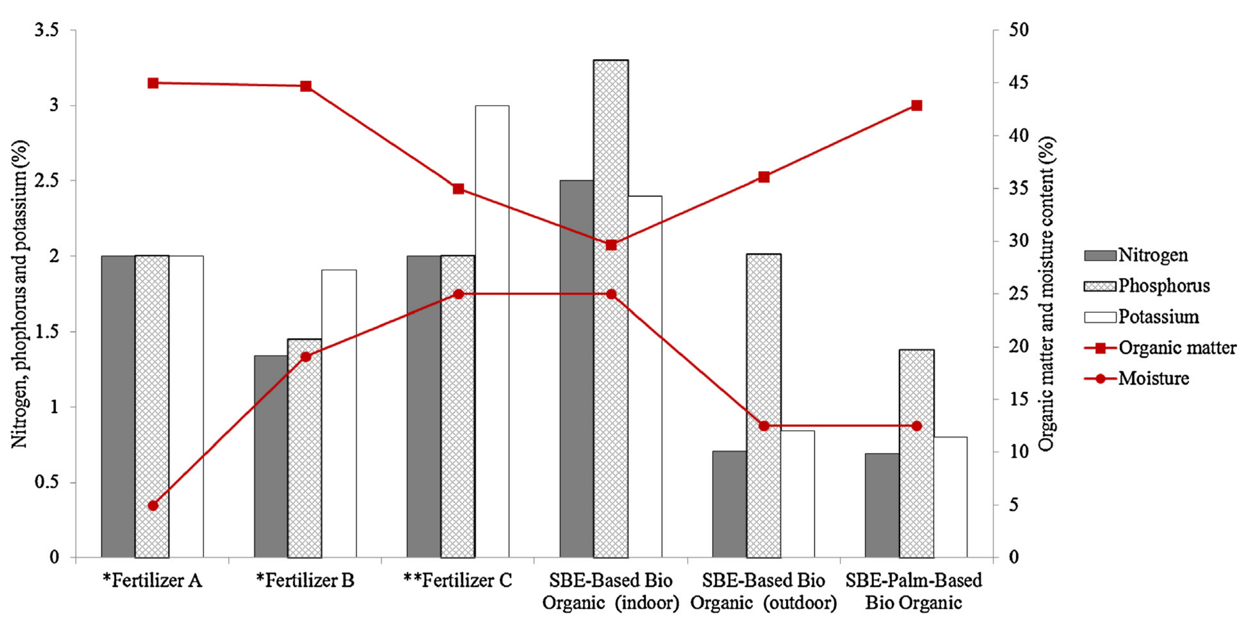

Fig. 1. Comparison of nutrient levels (%) between spent bleaching earth (SBE)-based bio organic and other commercial organic fertilizers (A, B, C).
*Data obtained from commercially available organic fertilizer packaging labels.
**Fertilizer specification by Ministry of Agriculture, Malaysia.

was evident that this was attributed in part to an active microbial rejuvenation during the composting in consuming the residual oil. The increase in water-holding capacity also was indicative of an increase in total porosity.

3.4. Characteristics of SBE-based bio organic fertilizer

The novel composting method has the ability to modify the morphology of the clay structure in SBE, in remedying and improving other chemical attributes besides eliminating the acidic and hydrophobic nature of the earth. The resulting SBE has been transformed into an effective bio organic material with improved organic carbon (OC) content from 7.1 to 16.5%, the CEC from 8.0 to 33.8 cmol/kg, the water-holding capacity from 6.1 to 16.5 ml/100 g and the C:N ratio from 290 to 9–21. The OC increased due to the residual oil in SBE and the high OC content of the co-composted materials. Most of the degradable organic matter was decomposed and replenished. An increase in OC after composting would have contributed to the observed increase in CEC, thereby enhancing the nutrient supplying capacity of the bio organic fertilizer made. Surprisingly, the C:N ratio improved tremendously after composting. This showed that the microorganisms present in SBE, 8000 colonial form unit (CFU) in 10 mL of diluted SBE supernatant, had utilized the residual oil and the organic matter readily available in SBE as carbon source to manipulate and transform SBE into a suitable base material facilitating microbial activities.

When SBE is associated with soil, the CEC of soil will be improved (Table 4) by weakly binding the exchangeable cations onto the negatively charged soil surface via electrostatic forces. The CEC of the mineral soil mixed with composted SBE at SBE:soil ratio of 50:50 has increased from its original 8 cmol per kg to 32–39 cmol per kg. This is indicative of an increase in organic matter (source of negative electrostatic sites), thus an increase in ability of the soil to exchange, attract and retain nutrient elements from SBE in a loosely bound bonding. This will prevent nutrient loss via leaching by allowing plants to extract them from the soil via 'swapping' them with H^+.

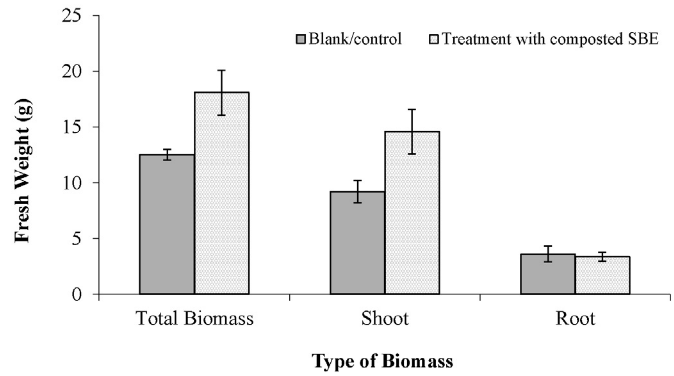

Fig. 2. Fresh matter production (total biomass, shoot and root) of kangkung in a pot trial after a month of cultivation with composted spent bleaching earth (SBE).

The high CEC is also indicative of greater water-holding capacity and slow release of water/nutrients once it is mixed and activated with soil. It holds 20 mL of water per 100 g of SBE while soil mixed with composted SBE (50:50) can hold up to 140 mL of water (Table 4). The resulting bio organic material thus has a slow release property in managing the controlled-released efficiency of nutrients and water in soil–fertilizer interaction. This is because the transformed SBE tends to entrap/encapsulate volatile nutrient elements (such as N) and then releases them slowly into the soil it is applied to. An optimal C:N ratio ranged 9–21 in SBE-formulated bio organic fertilizer was achieved approaching C:N ratio for adequate microbial soil function, thus shows evident that it contributes to

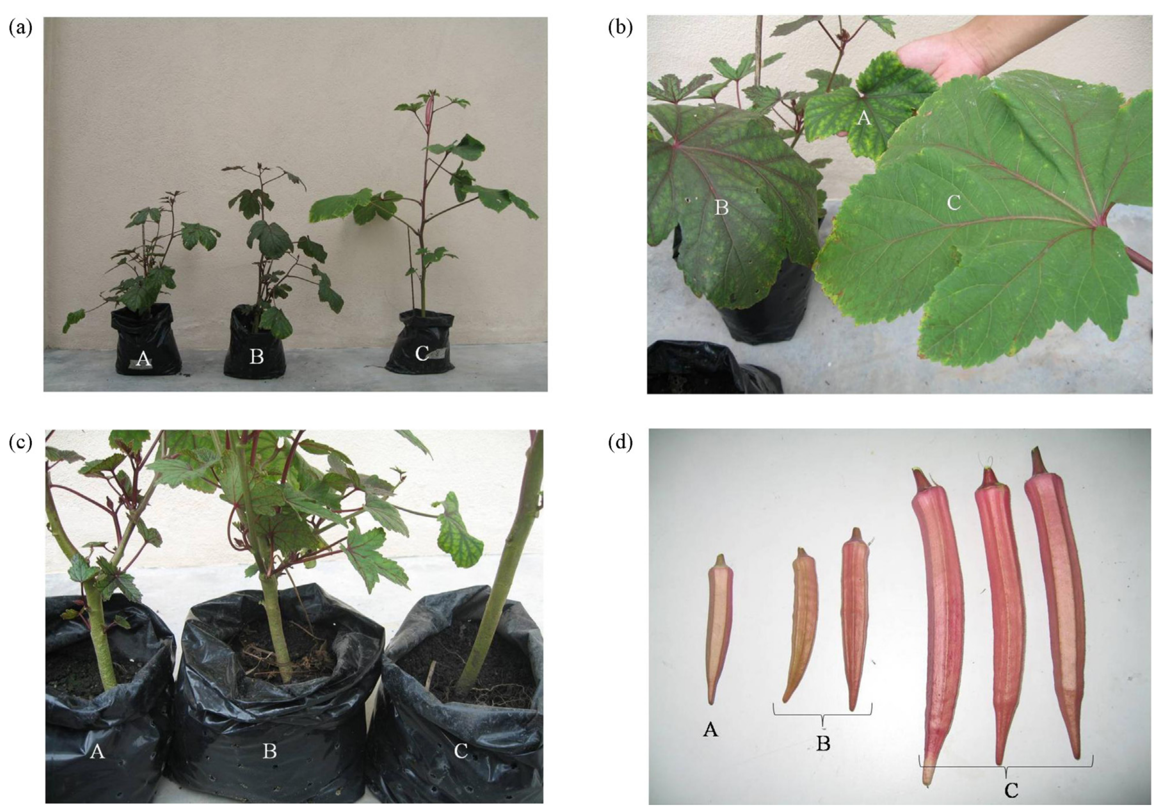

Fig. 3. Comparison of the plant growth performance [(a) height of plant, (b) size of leaf, (c) stem diameter and (d) fruit size] of okra in different fertilizer treatment (A) Control, (B) chicken litter and (C) composted spent bleaching earth (SBE), after a 3-month field trial.

Table 5
Example of results of a field trial on groundnut var. magenta using composted spent bleaching earth (SBE).

Parameter [per plot (0.5 ha) basis]	Composted SBE-based bio organic fertilizer	Standard fertilizer package
Average plant height (cm)	61.3	100.1
No. of pods		
1 pod	195	110
2 pods	351	226
3 pods	3	2
% of 2 pods	64	67
Average fresh weight (g)	1201.2	756.2

plant nutrition when applied to the soil, and that it is superior to other commercial organic fertilizers (Fig. 1) in terms of biological decomposition of organic residue and bioavailability of C, N and P.

The SBE-based bio organic fertilizer is favourably pelletized to give good binding effect to the fertilizer due to the presence of "natural binder" vis-à-vis the residual oil in SBE.

3.5. Performance of pot and field trials

Small scale pot assays was conducted on (i) *I. aquatic* or kangkung and (ii) *A. esculentus* or okra, using composted SBE as a bio organic fertilizer.

3.5.1. Ipomoea aquatic or kangkung

The *t*-test of the fresh weights of the total biomass (whole plant) and the selected parts of the harvested biomass (shoot and root) after a month of cultivation showed, on average, a more significant growth of the plant's shoot ($p = 0.02$) than that of its root ($p = 0.72$) and clearly demonstrating an overall 50% increase in kangkung fresh weight production ($m = 18.1$, SD = 2.0, $t(3) = 3.2$, $p = 0.018$) for the plants treated with composted SBE compared to that without treatment ($m = 12.5$, SD = 0.5) (Fig. 2). It was observed that kangkung treated with composted SBE has a better germination rate, more leaves and healthier growth compared to the control.

3.5.2. Abelmoschus esculentus or okra

It was observed that okra treated with composted SBE improved significantly in the plant height (Fig. 3a), the size of the leaf (Fig. 3b), the stem diameter (Fig. 3c), the yield and the fruit size (Fig. 3d) compared to that of the plants without treatment. The treated okra had healthier growth too.

The *t*-test of the fresh weights of the total biomass (whole plant) and the selected parts of the harvested biomass after a month of cultivation with the composted SBE showed significant improvements on the overall plant growth and fruit yield (Fig. 4a). The results showed an overall 2- to 3-fold increase in okra fresh weight production – for the total biomass ($m = 19.8$, SD = 1.7, $t(4) = 2.8$, $p = 0.0003$) and for the fruit ($m = 16.1$, SD = 1.5, $t(3) = 3.2$, $p = 0.003$). Under the same treatment and after a complete 3-month trial, the okra plants demonstrated insignificant growth in both the root ($p = 0.18$) and leaf ($p = 0.70$) in the dry weight basis. However, there is enough evidence ($p = 0.01$ and 0.04, respectively for the fresh and dry fruit weights which are $< \alpha = 0.05$) to show that the yield productivity of okra for this treatment increased significantly i.e. 60% for fresh yield and 37% for dry yield, respectively (Fig. 4b).

The observations conducted on the big scale field evaluation and efficacy testing showed that there was a significant increment (~60%) in the fresh weight of groundnut magenta (Table 5). It was observed that the plot treated with composted SBE-based bio organic fertilizer in groundnut magenta cultivation showed less population of wild grass as well as having brighter leaf colour and clear leaf bones.

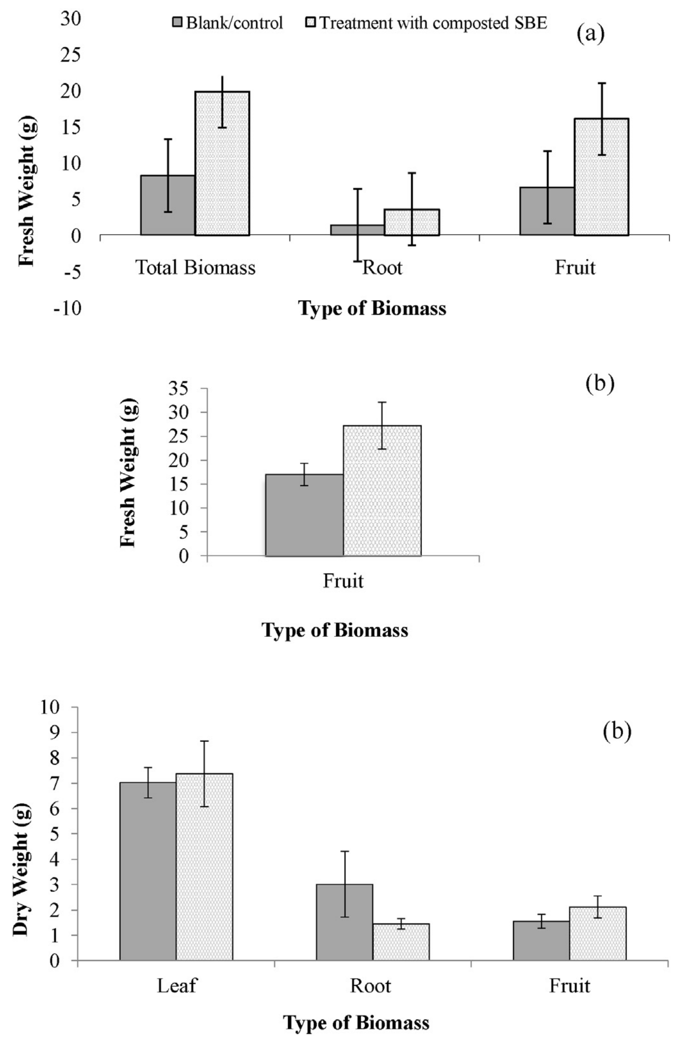

Fig. 4. Fresh and dry matters production of the selected harvested biomass of okra in a pot trial at (a) a month and (b) 3 month of cultivation with composted spent bleaching earth (SBE).

Hence, the pot and field trials that have been conducted so far showed that composted SBE-based bio organic fertilizer enhances soil fertility, promotes rapid root and plant growth, and improves crop quality while increasing crop productivity and yield. Currently, some trials are under way to investigate the effects of this organic fertilizer on oil palm productivity. Nevertheless, it would be of interest to focus on incorporating SBE with other wastes generated for potential application on a wide range of other crops in the future.

4. Conclusion

Through composting SBE with agricultural and palm oil milling by-products, the physicochemical properties such as the acid reactivity and hydrophobic nature of the composted SBE improved drastically. The resulting compost exhibited some enhanced fertilizer properties such as the C:N ratio, water-holding capacity, CEC and OC content that was able to rejuvenate degraded soil, and to act as an efficient water/nutrients controlled release fertilizer in soil–fertilizer interaction. Results from the pot assays and field trial conducted further revealed a significant biomass growth and yield productivity for the tested crops. In general, the developed SBE compost can be used as a bio organic fertilizer for a wide range of crops.

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References

ASTM, 2010. American Society for Testing and Materials (ASTM) ASTM D2980-04(2010) Standards Test Method for Volume Weights, Water Holding Capacity, and Air Capacity of Water Saturated Peat Materials. ASTM International, West Conshohocken, PA, 2010, http://dx.doi.org/10.1520/D2980-04R10 www.astm.org

ASTM, 2009. American Society for Testing and Materials (ASTM), ASTM 5142-09 Standard Test Methods for Proximate Analysis of the Analysis Sample of Coal and Coke by Instrumental Procedures. ASTM International, West Conshohocken, PA, http://dx.doi.org/10.1520/D5142-09 www.astm.org

ASTM, 2002. American Society for Testing and Materials (ASTM) ASTM D5373-93(2002) Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Laboratory Samples of Coal and Coke. ASTM International, West Conshohocken, PA, 2002, http://dx.doi.org/10.1520/D5373-93R02 www.astm.org

Arias-Estévez, M., López-Periago, E., Nóvoa-Muñoz, J.C., Torrado-Agrasar, A., Simal-Gándara, J., 2007. Treatment of an acid soil with bentonite used for wine fining: effects on soil properties and the growth of *Lolium multiflorum*. J. Agric. Food Chem. 55, 7541–7546.

Aziz, A.R., Harcharan, S., Elkanzi, E.M., Lam, L.S., Liew, S.H., 2001. Feasibility study of oil recovery from used bleaching earth using waste solvents. In: Proceedings of Palm Oil Research Institute Malaysia (PORIM), International Palm Oil Congress (PIPOC), pp. 126–133.

Bermúdez-Couso, A., Fernández-Calviño, D., Pateiro-Moure, M., Nóvoa-Muñoz, J.C., Simal-Gándara, J., Arias-Estévez, M., 2011. Adsorption and desorption kinetics of carbofuran in acid soils. J. Hazard. Mater. 190, 159–167.

Chanrai, N.G., Burde, S.G., 2004. Recovery of oil from spent bleaching earth. US Patent No. 6,780,321 B2.

Cheah, K.Y., Siew, W.L., 2004. Regeneration of spent bleaching clay. Malaysian Palm Oil Board (MPOB) Information Series 237, MPOB TT No. 230. Available from: http://palmoilis.mpob.gov.my/publications/TOT/TT-230.pdf

Chen, Q., Zhang, X.S., Zhang, H.Y., Christie, P., Li, X.L., Horlacher, D., Liebig, H.P., 2004. Evaluation of current fertilizer practice and soil fertility in vegetable production in Beijing region. Nutr. Cycling Agroecosyst. 69 (2004), 51–58.

Croker, J., Poss, R., Hartmann, C., Bhuthorndharaj, S., 2004. Effects of recycled bentonite addition on soil properties, plant growth and nutrient uptake in a tropical sandy soil. Plant Soil 267 (2004), 155–163.

Damodaran, R., 2008. Ecooils Invests RM6.5m in Second Plant. New Strait Times, Business News, Malaysia.

Ho, S.P., Yuan, S.T., Jien, S.H., Hseu, Z.Y., 2010. Elucidating the process of co-composting of biosolids and spent activated clay. Bioresour. Technol. 101, 8280–8286.

Loh, S.K., Choo, Y.M., Ma, A.N., 2007. Residual oil from spent bleaching earth (SBE) for biodiesel and biolubricant applications. Malaysian Palm Oil Board (MPOB) Information Series 381, MPOB TT No. 367. Available from http://palmoilis.mpob.gov.my/publications/TOT/TT-367.pdf

Loh, S.K., Cheng, S.F., Choo, Y.M., Ma, A.N., 2006. A study of residual oils recovered from spent bleaching earth: their characteristics and applications. Am. J. Appl. Sci. 3 (10), 2063–2067.

Ng, W.K., Koh, C.B., Din, Z.B., 2006. Palm oil-laden spent bleaching clay as a substitute for marine fish oil in the diets of Nile tilapia, *Oreochromis niloticus*. Aquacult. Nutr. 12 (6), 459–468.

Nóvoa-Muñoz, J.C., Simal-Gándara, J., Fernández-Calviño, D., López-Periago, E., Arias-Estévez, M., 2008. Changes in soil properties and in the growth of *Lolium multiflorum* in an acid soil amended with a solid waste from wineries. Bioresour. Technol. 99 (15), 6771–6779.

Park, E.Y., Kato, A., Ming, H., 2004. Utilization of waste activated bleaching earth containing palm oil in riboflavin production by *Ashbya gossypii*. J. Am. Oil Chem. Soc. 81 (1), 57–62.

Pateiro-Moure, M., Nóvoa-Muñoz, J.C., Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., 2009. Quaternary herbicides retention by the amendment of acid soils with a bentonite-based waste from wineries. J. Hazardous Mater. 164 (2–3), 769–775.

Rayment, G.E., Higginson, F.R., 1992. Australian Laboratory Handbook of Soil and Water Chemical Methods. Inkata Press, Melbourne, Australia.

Soda, W., Noble, A.D., Suzuki, S., Simmons, R., Sindhusen, L., Bhuthorndharaj, S., 2006. Co-composting of acid waste bentonites and their effects on soil properties and crop biomass. J. Environ. Qual. 35, 2293–2301.

Soda, W., Noble, A.D., Suzuki, S., Simmons, R., Sindhusen, L., Bhuthorndharaj, S., 2005. Composting of bentonite wastes from vegetable oil processing with rice husk, rice husk ashes and chicken litter to lower the hydrophobicity and acid reactivity of bentonite wastes. In: Proceeding of The XV International Plant Nutrition Colloquium, Beijing, China, pp. 1186–1187.

SIRIM, 1980. Standards and Industrial Research Institute of Malaysia (SIRIM). Recommended Methods for Soil Chemical Analysis MS678: Part I to V, Malaysia.

Walkley, A., Black, I.A., 1934. An examination of the degtjareff method for determining soil organic matter and prepared modification of the chromic acid titration method. Soil Sci. 34, 29–38.

Wang, X.Q., Zhang, J.Q., Liu, B.H., Qiu, D.L., 2010. Spent bleaching clay (SBC) from oil refining as a substrate for the spawn production of shiitake mushroom (*Lentinula edodes*). Afr. J. Biotechnol. 953, 9007–9011.

Zulkifli, H., Masnon, Z.M., 1993a. PORIM Soil Analysis Manual Part 1 Soil Analysis (9.1): Determination of Organic Carbon (Walkley and Black), Biology Division. Palm Oil Research Institute Malaysia (PORIM), Bangi.

Zulkifli, H., Masnon, Z.M., 1993b. PORIM Soil Analysis Manual Part 1 Soil Analysis (10.1): Determination of Total Nitrogen, Biology Division. Palm Oil Research Institute Malaysia (PORIM), Bangi.

Zulkifli, H., Masnon, Z.M., 1993c. PORIM Soil Analysis Manual Part 1 Soil Analysis (11.1): Determination of Total Phosphorus, Biology Division. Palm Oil Research Institute Malaysia (PORIM), Bangi.

Zulkifli, H., Masnon, Z.M., 1993d. PORIM Soil Analysis Manual Part 1 Soil Analysis (13.0): Determination of Cation Exchange Capacity (CEC) by Leaching Method, Biology Division. Palm Oil Research Institute Malaysia (PORIM), Bangi.